The Lambert Peninsula, Ku-ring-gai Chase National Park. Physiography and the Distribution of Podzols, Shrublands and Swamps, with Details of the Swamp Vegetation and Sediments

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The Lambert Peninsula is asymmetric, with deeply-dissected V-shaped valleys on the western side and on the eastern side extensive areas with low slope (less than 5°). Podzols, shrublands and swamps on the peninsula have been mapped using aerial photographs and ground confirmation. All podzol soils, the majority of swamps and most of the shrublands occur on areas of low slope. Areas of low slope underlain by clayey sandstone (puggy material) and extensive sandstone benches lead to poorly-drained soils and development of moist shrublands. In even less well-drained conditions swamps form, both on valley floors and valley sides. The vegetation of the swamps is divided into four types using the characteristic height and abundance of some of the larger conspicuous species. The anomalous distribution of two of the swamp species, *Banksia robur* and *Gymnoschoenus sphaerocephalus*, on the peninsula is mapped. The iron/organic-rich sediments which have accumulated in swamps to depths varying between a few centimetres and 2 metres are described. The influence of climatic fluctuations on the extent of moist shrublands and swamps is discussed.

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INTRODUCTION

The Lambert Peninsula in Ku-ring-gai Chase National Park, on the northern edge of Sydney (Fig. 1), is an area of great beauty and botanical interest. The scenic attraction of the West Head Lookout at Broken Bay, the numerous walking trails, and the proximity to Sydney create intense pressure on the area. Yet knowledge of the biology of the area is minimal and no detailed vegetation maps or physiographic studies hitherto have been available for the area.

This paper is a first attempt to describe the general physiography of the Peninsula and to map the distribution of shrublands, of swamps, and of plant communities growing on podzolized sand accumulations on the plateau surface. An attempt is made to relate the swamps, the shrublands and the podzol communities to the physiography and geology of the peninsula. Only passing comment is made on the woodlands and forests of the area, and the vegetation on the dykes and on the Triassic Narrabeen Group is not mentioned. This group is only revealed near sea level whereas the gentle undulating plateau surface, broken by steep gullies, has been produced by weathering and erosion of the overlying Hawkesbury Sandstone.

The depositional environment of the Hawkesbury Sandstone is still under debate (Ashley and Duncan, 1977). The sedimentation units are near horizontal on a regional scale, but are commonly cross-bedded. It is an argillaceous iron-rich quartz sandstone, with the grain size commonly medium to coarse (Standard, 1969). The soils have a sandy top soil often overlying a more clayey sub-soil (Gradational Gn, or duplex Dy soils; Northcote, 1971) but in two regional surveys (Walker, 1960; Hamilton, 1976) the soils of this sandstone have been mapped as uniform sandy soils. Shale is infrequent in the Hawkesbury Sandstone sequence but on the eastern surface of the Lambert Peninsula a clayey material is quite widespread. The texture can vary from a clayey sand to clay over short (approximately 1 m) distances, both laterally and vertically, and subsurface layers of these beds are usually weathered to a pliable

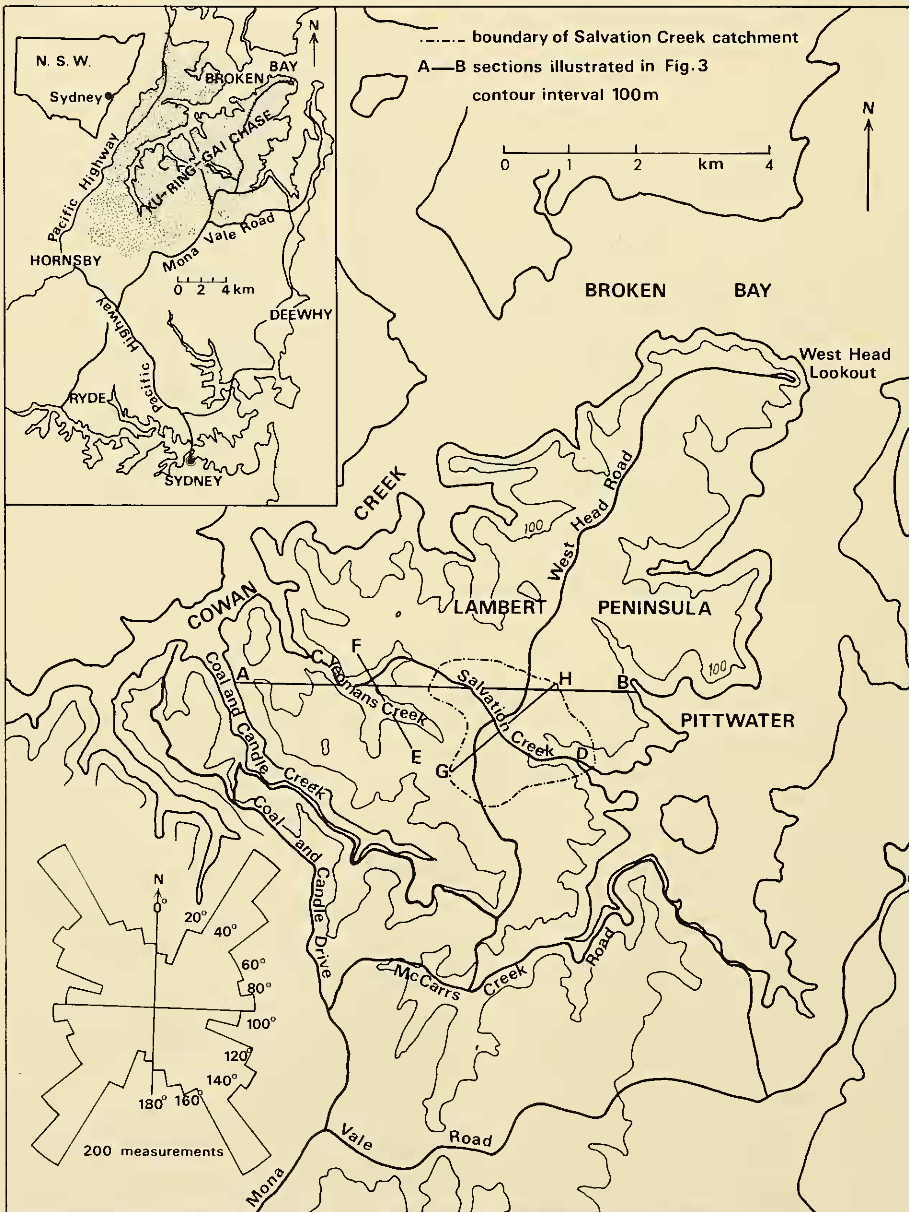

Fig. 1. Location map of the study area and a joint rose from the Salvation Creek catchment.

consistency. It is usually moist; the colour is whitish grey or, in places, mottled red to yellow. It will be referred to as puggy material.

Shale beds in the Hawkesbury Sandstone impede drainage and aid the development of swamps (Davis, 1936; Hannon, 1956; Lamy and Junor, 1965; Holland, 1974). Comparatively level areas and extensive sandstone layers can also cause deficient drainage (Pidgeon, 1938; Lamy and Junor, 1965). The term 'swamp' has long been applied to the wet areas around Sydney (for example by Hamilton, 1915) but more recently in Specht, Roe and Boughton (1974) the term 'fen' has been applied to areas dominated by *Gymnoschoenus sphaerocephalus* in Ku-ring-gai Chase. The traditional word 'swamp' is used here to describe the diverse wetlands on the peninsula.

Holland (1974) divided the swamps of the Blue Mountains (approximately 70 km west of Sydney) into two topographic types, valley-floor and valley-side, but did not name the swamps with both components. Sufficient examples of this type occur on Lambert Peninsula to warrant classifying these as a third group — composite swamps.

Pidgeon (1938) classified the swamps of the Hornsby Plateau, an area which includes Lambert Peninsula, into two vegetative types. One category was the shrub swamps, which are either classified with the driest swamp type or, more generally, grouped with moist shrubland in this paper. Pidgeon (1938) called the second type sedge swamps, and from the species list and description provided, this type covers a wide range of soil moisture. The dominant species listed typify the drier swamps on the peninsula and the large areas (up to approximately 3 ha for a single swamp) of the wetter types on the peninsula only receive a very brief mention as occurring in soaks and drainage channels. The swamps between McCarrs Creek and West Head, which were grouped as sedge swamps by Pidgeon (1938), are subdivided and described as four different swamp types.

Methods

Aerial photographs (at a scale approx. 1:14 000) were used to locate and map shrublands, swamps and podzols and for measurement of joint orientations. The ease with which features such as vegetation boundaries and joints in rock outcrops can be seen on these photographs varies with the time since a fire. As the vegetation regrows after a fire, the early stages are insufficient to define features, and at later stages dense regrowth may obscure some detail. Aerial photographic interpretation on Lambert Peninsula is easiest approximately ten years after a fire. Identification of features was confirmed by field examination.

The base maps for Figs 1, 4 & 5 were adapted from 1:63 360 Broken Bay sheet and 1:100 000 Sydney sheet 9130. Fig. 2 was compiled from aerial photographs (Cumberland 1970) and N.S.W. 1:25 000 ortho-photomaps Broken Bay, Hornsby, Cowan and Mona Vale. Sections across the peninsula (Fig. 3) were derived from the N.S.W. Department of Lands map, Ku-ring-gai Chase 1:25 000.

All swamp profiles were measured using an Abney Level. After initial samples of subsurface layers were obtained using a two inch auger, a length of steel re-inforcing rod pushed into the ground was generally sufficient to locate sand, puggy material, swamp fill layers and the podzol pan between successive auger holes.

Botanical names are those used in Beadle, Evans and Carolin (1972) except for some recent name changes.

The Shape of the Peninsula

The directions of the western and eastern boundaries of the peninsula, Cowan Creek and Pittwater, and the southern boundary, Coal and Candle Creek (Fig. 1) are

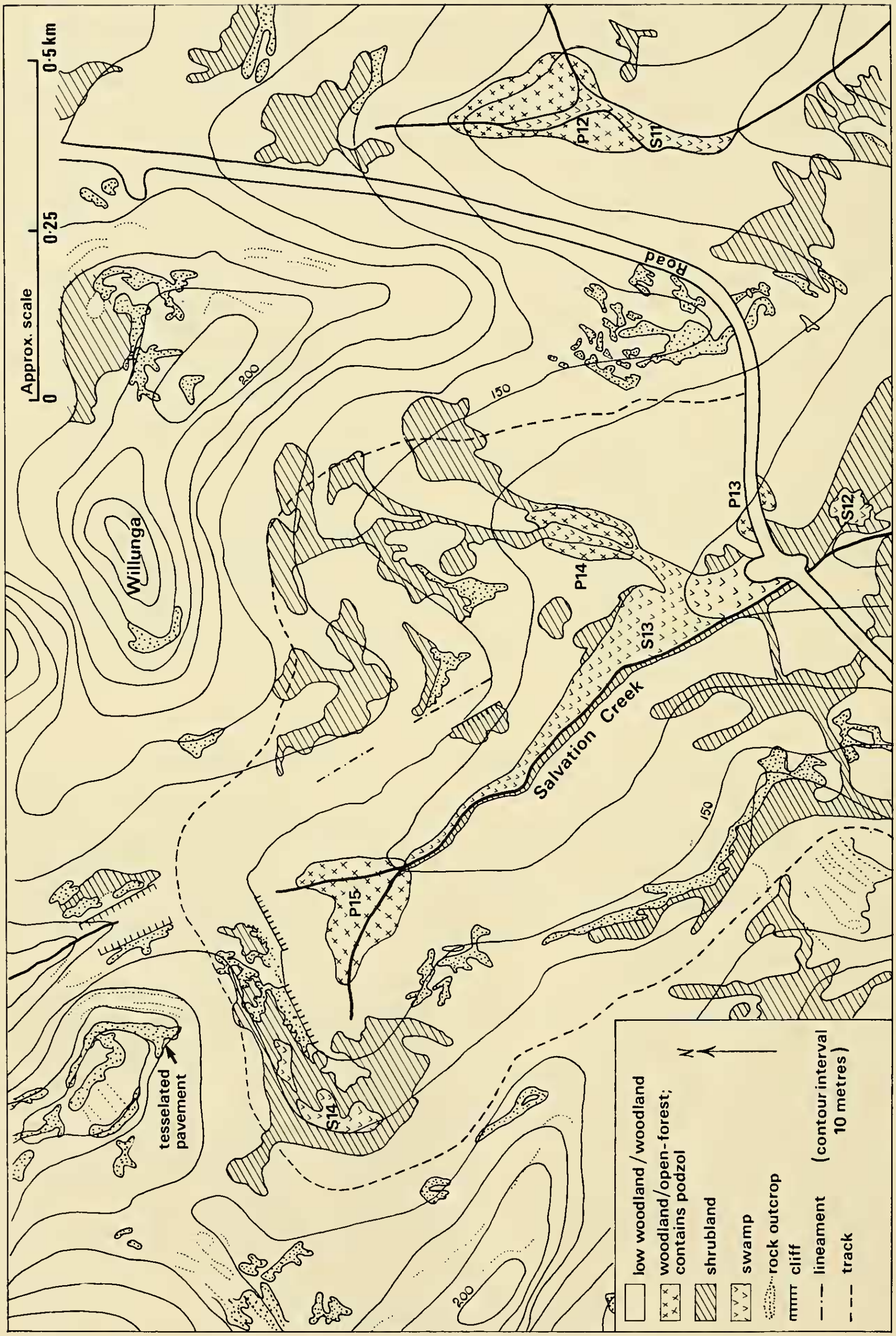

Fig. 2. Map of the upper Salvation Creek catchment.

probably controlled by NE-SW and NW-SE joints respectively, since these boundaries correspond to regional joint orientations (Mabbutt, 1970). Joint-control of cliffs, creeks and swamps, and vegetation boundaries is obvious throughout the peninsula and can be observed in the field and on aerial photographs. The joint rose in Fig. 1 is compiled from measurements made from aerial photographs of the Salvation Creek catchment. Joint measurements from ground survey in this catchment also show predominant NE-SW and NW-SE directions, and many features in the upper Salvation Creek area follow these orientations (Fig. 2). For example, Salvation Creek and the creek draining Swamp 11 both drain SE. The cliffs defining a trench-like valley north of Podzol 15 are orientated NW-SE and are approximately in line with a cliff and a lineament (revealed as a joint and a gap in the tree canopy along different parts of its length) in the Salvation Creek Catchment. The NE-SW orientation is less frequently exploited but one example is the cliffs near Swamp 14.

The peninsula is asymmetric about the divide running approximately N-S (Fig. 4). West of the divide it is deeply dissected by V-shaped valleys but on the eastern side, shallow basin-shaped valleys are present (Fig. 3, section A-B). For example, (Fig. 3, section C-D), the westerly flowing Yeomans Creek has deeply eroded headwaters, a middle course with a gentle slope, followed by a short steep fall to Cowan Creek. The headwaters and middle section of Salvation Creek cross a gentle easterly sloping surface, beyond which the creek falls steeply to Pittwater. Cross sections halfway along

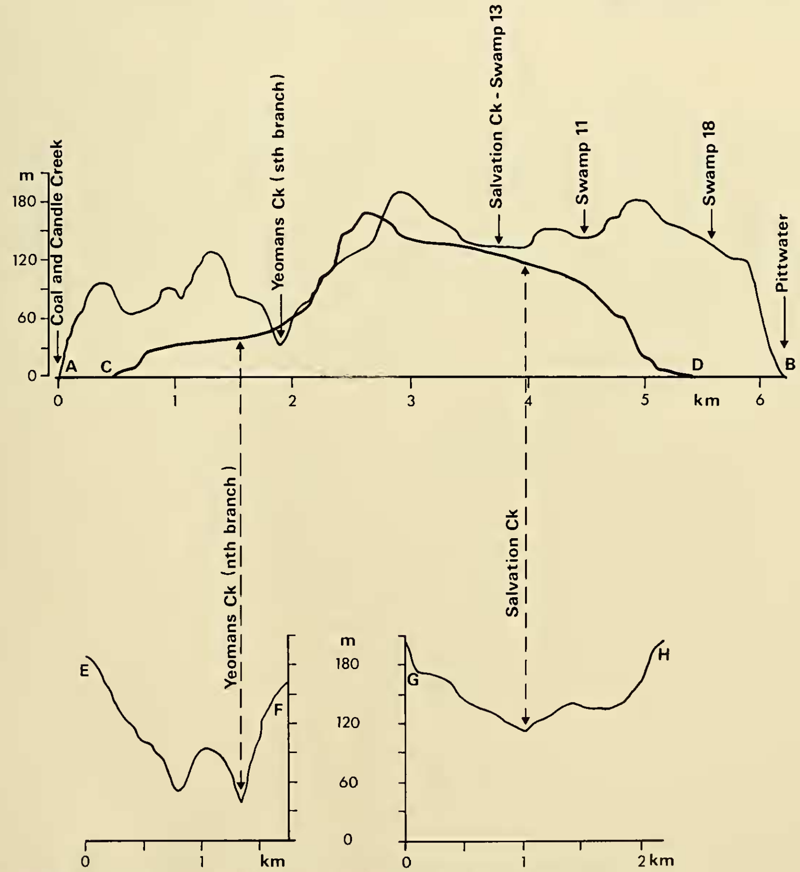

Fig. 3. Topographic sections of the Lambert Peninsula. Sections located on Fig. 1.

these creeks (Fig. 3, sections E-F, G-H) show that the Yeomans Creek valley is steep-sided and narrow, while Salvation Creek occupies a broad valley with gently sloping sides.

Steep slopes (Slope Class 1, slope >15-20°) are virtually restricted to the coastal cliffs and some deep gullies on the eastern half of the peninsula, but on the western side these slopes intrude deeply (Fig. 4). The intermediate slope class (Class 2, 5° to 15° or 20°) covers large areas on both sides of the peninsula, but it is most common on

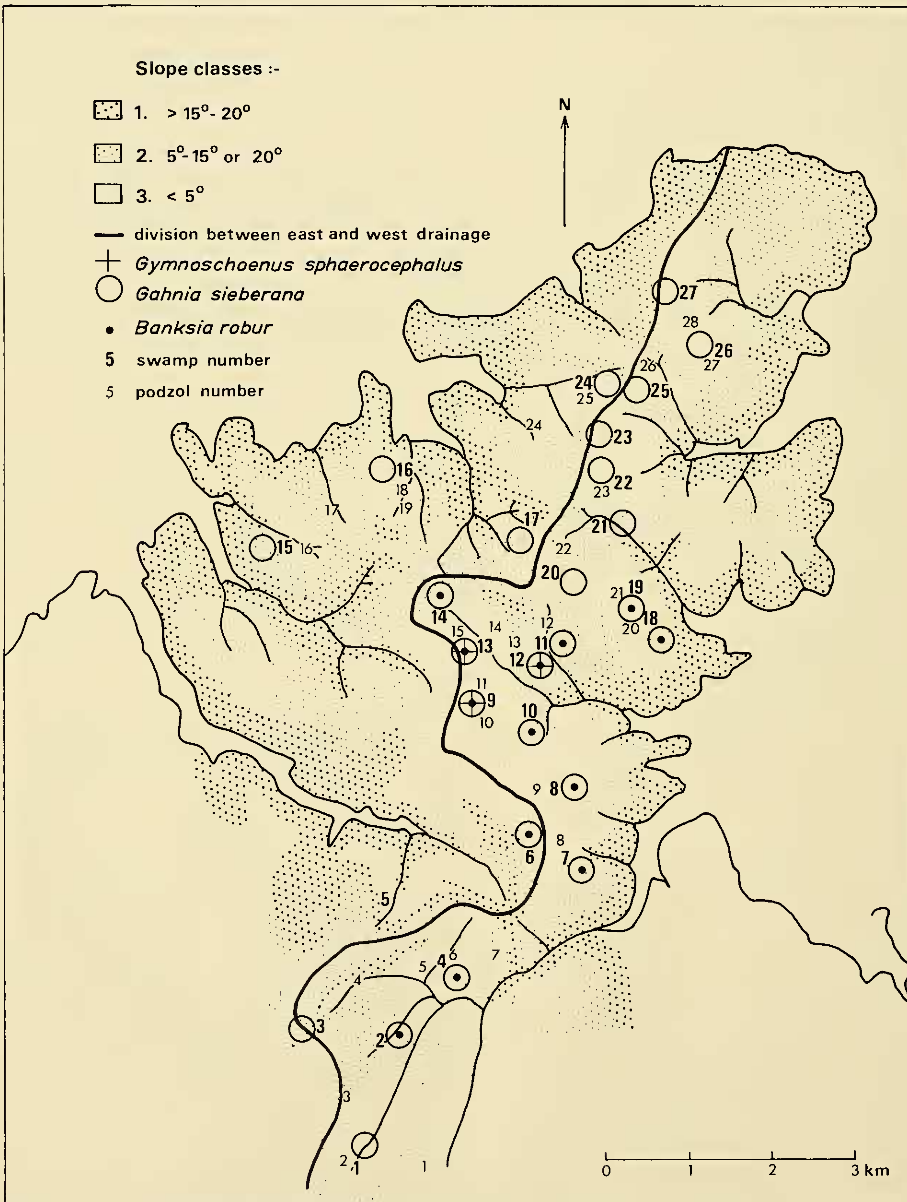

Fig. 4. The distribution of the three slope classes, podzols, swamps and three swamp plants, *Gymnoschoenus sphaerocephalus, Gahnia sieberana* and *Banksia robur.*

the western half. The most gentle slope class (Class 3, <5°) is almost confined to the eastern side, with only very small areas present in the west.

The causes of the asymmetry are not known but the gentle easterly slope of the surface of the Hawkesbury Sandstone and the easterly trend of the cross-beds (Standard, 1969) may be responsible.

Podzols

Podzol soils on the sandstone plateaux have only recently been described in detail (Buchanan and Humphreys, 1980) and the vegetation characteristic of these soils was first mentioned in the above paper.

All twenty-eight podzol soils (at grid references listed in Appendix 1) which were found on the peninsula occur in low slope areas (Fig. 4). Only six of these are on the western side and these six occur in isolated small areas with a gentle slope. Podzol soils develop in deep (1-4 m) quartz sand deposits which may cover an area from less than 0.1 ha to approximately 5 ha. These deposits frequently occur near creeks or swamps. The vegetation growing on these soils is very similar throughout the peninsula. The trees are usually taller (open-forest/woodland; Specht, 1970) than the surrounding *Eucalyptus haemastoma* Sm. association of low open-forest/low woodland. They can therefore be identified on aerial photographs with a high degree of confidence using the characteristics of gentle slope and taller vegetation, and in the field, the floristics of the tree and understorey layers aids identification of these soils (Buchanan and Humphreys, 1980).

Shrublands

The term shrubland has been selected as the clearest description of shrub-dominated areas, although it has been used in vegetation classifications (Specht, 1970; Forster, Campbell, Benson and Moore, 1977) to refer to shrub communities of specific height and density. The shrub-dominated areas on the peninsula fit into many categories in these detailed classifications and the term shrubland in this paper does not imply a specific height or density of shrubs. In a floristic survey of Ku-ring-gai Chase, Outhred, Lainson, Lamb and Outhred (in preparation) classify shrub-dominated areas in a fashion broadly consistent with that adopted by Specht.

The distribution of shrublands does not appear to be influenced by aspect or shelter (Pidgeon, 1938) but rather by soil depth and drainage. Fairly extensive areas of shrubland interspersed with rock outcrops occur on the peninsula, especially at the northern end (Fig. 5). Shrublands develop in these areas as resistant sandstone beds near the surface prevent trees becoming established. However, much of the shrubland is not broken up by rock outcrops and the presence of shrubland in these areas is controlled by a number of factors, all of which result in poorly drained soils. The majority of these moist shrublands have a low surface slope and are most common on the gentle slopes on the eastern side of the peninsula. A puggy material is often present approximately 1 m or less below the surface and it effectively prevents rapid drainage. Extensive sandstone benches also impede drainage and many moist shrublands are perched on benches with the sandstone revealed on the downslope side (Fig. 2). The extremely broken topography of the western half of the peninsula does not allow impeded drainage except on small benches.

On the eastern half, the boundary between shrubland and trees is sometimes ill-defined but it is frequently very sharp and coincides with the change from a poorly-drained to a well-drained soil. Observation during and after torrential rain showed that the surface soil under the trees never became waterlogged but the shrubland soil became waterlogged, and remained so for days. This rapid change in soil drainage may occur over as short a distance as several metres, and matches exactly the tree/shrub boundary. The most spectacular examples have a very obvious change in understorey as well, and are often the result of an abrupt junction between clayey sandstone and sandstone (Fig. 6). An equally sharp shrub and tree boundary, but a more gradual change in the understorey, takes place when the clayey sandstone thins or deepens beneath the trees.

Many of these moist shrubland/tree boundaries obviously occur at joints which mark this change in rock type and involve little or no change in surface topography.

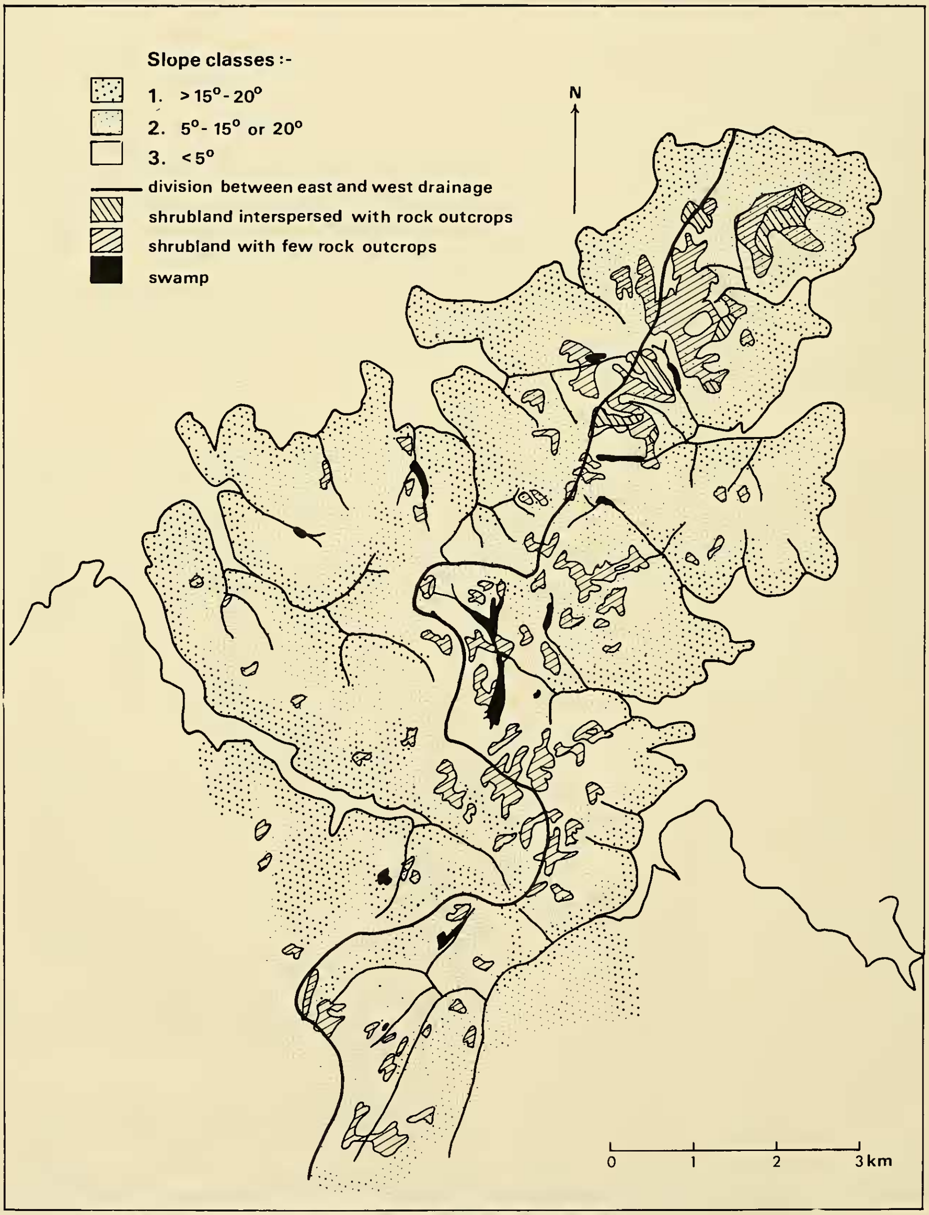

Fig. 5. The distribution of the three slope classes, shrubland and swamps.

Joints which control the direction of cliffs often mark a change in vegetation as well as surface elevation. Fig. 2 shows a clear example of shrubland on a rock shelf and an area covered by trees immediately below the cliff north-west of Podzol 15. Rapid changes in surface and subsurface slope can also cause an abrupt change in soil drainage.

Swamps

The distribution of swamps in the West Head to McCarrs Creek area is strongly controlled by lithology and topography. Areas need a fairly constant inflow of water as well as a slow loss of water for swamps to develop. The simplified and generalized longitudinal section of the swamps on the peninsula (Fig. 6) shows the suitable conditions for swamp development.

The first requirement is a gentle slope. Twenty-three of the twenty-seven mapped swamps (grid references listed in Appendix 2) occur in areas with a slope of 5° or less (Fig. 4). Only two of the valley-floor swamps, which form along creeks, occur where the general surrounding slope is greater than 5° (Nos. 17 and 21) but all of the valley-floor swamps and valley-floor elements of composite swamps have a longitudinal slope between 0° and 3°. Some valley-floor swamps are probably situated directly on extensive sandstone benches in these near horizontal segments of the creek beds. Valley-side swamps are frequently perched on rock shelves on the valley slopes and may have a slope of up to 10°.

The second requirement is the presence of the puggy material in the swamp catchment. Water percolating vertically through the overlying sandy soil and sandstone beds will saturate the puggy material and water seeping from it provides a fairly slow and constant supply to the swamps in dry periods. This layer may sometimes continue laterally under readily-draining sandstone beds and, if this is so, the catchment of these puggy layers may be considerably larger than augering indicates. The presence of this puggy material near the surface is indicated by the presence of moist shrubland, and all swamps except No. 15 and the valley-side arm of No. 4 receive drainage from moist shrubland. The swamps may occur immediately

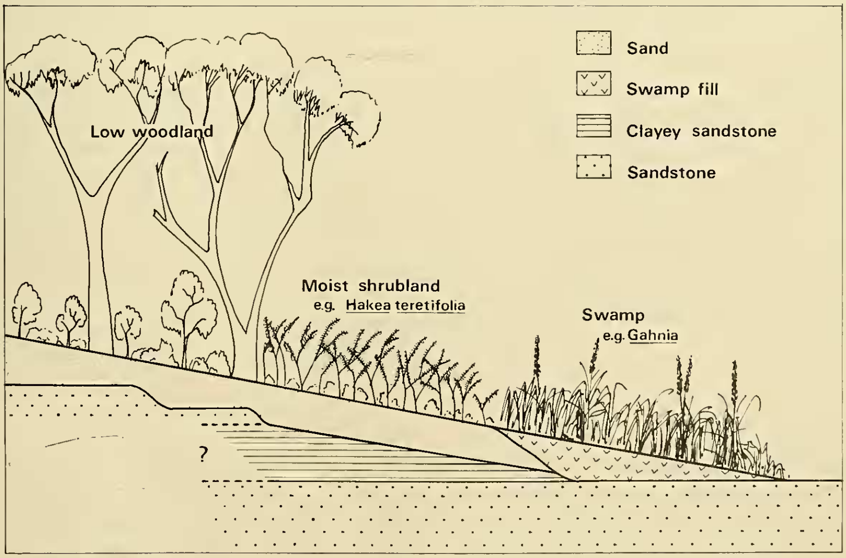

Fig. 6. Simplified and generalized longitudinal section of the swamps on the Lambert Peninsula.

downslope of such areas or they may be connected by a creek. Some swamps are directly underlain by the puggy material.

Physiographic Types

Valley-floor Swamps

Valley-floor swamps are linear, as they form along creeks. They have a cross sectional slope of 0° and a longitudinal slope of 0-3°.

Swamp 21 (Fig. 7a, Fig. 9a) is an example of the simplest type of valley-floor swamp, as there is no zonation between the tall, dense swamp vegetation and the low woodland (*sensu* Specht, 1970) growing on the adjacent steep, rocky slopes. The iron/organic swamp fill is up to 2 m deep and a thick layer of sand is present between the swamp fill and bedrock. The main creek channel is on the least sandy side of the swamp, immediately adjacent to the rocky slope. Swamp 11 (Fig. 7b) is an example of a common valley-floor type. In the area of the section, the gradual slope change along one side of the swamp has allowed a very narrow zone of short swamp vegetation to develop between the tall and dense swamp vegetation and the low woodland. In other places along this border a thin zone of dense *Banksia ericifolia* has developed and such fringes are fairly common on the peninsula. Many valley-floor and composite swamps have a short (0.5-2 m) steep sandy rise along the edge. A podzol soil supporting a distinctive podzol vegetation occurs on these rises (Buchanan and Humphreys, 1980).

Valley-side Swamps

These swamps are very variable but frequently have a fairly steep slope (3-8°) and are sometimes controlled by the underlying rock shelf. Hanging swamps described by Pidgeon (1938) are probably valley-side swamps perched on rock shelves.

Swamp 14 (Fig. 7c) is not controlled by cupping of the underlying rock shelf, as the shelf slopes upward at approximately the same angle as the soil surface, 3°-7°. No creeks drain into this swamp so water levels must be maintained by downslope seepage, and drainage is probably impeded by the relative scarcity of joints in the rock shelf. The vegetation types indicate fairly dry conditions, as only a narrow zone of dense swamp vegetation occurs. Broader zones of short vegetation occur on either side of the wettest area and the usual fringe of mixed vegetation is present along the rock shelf boundary.

Swamp 4 (Fig. 8d, Fig. 9c) is the steepest (slopes up to 14°) in the area and it is the only example of the following type. A cliff 4 m high above a puggy material layer occurs at the upslope edge of the swamp. The presence of tall and dense swamp vegetation at the base of the cliff, as well as the geological relations, indicate that water draining from the overlying sandstone seeps out of the clayey layer at the base of the cliff. Further downslope, drier conditions only enable a swamp with short vegetation to form. Sand washed down the slope has accumulated in irregularities in the bedrock, giving the hillside a smooth rather than terraced profile. The iron/organic fill forms a continuous skin over the sand and rock. On each side this hillside swamp is bordered by well-drained soils carrying a low woodland of *Eucalyptus haemastoma,* and the boundary between swamp and low woodland is remarkably sharp.

Composite Swamps

These swamps consist of a valley-floor element and the bordering gentle (0-3°) hillslope. A decrease in soil moisture and a greater fluctuation in soil moisture occurs from the valley-floor up to the hillslope. The water-table fluctuations are influenced by such features as the surface and bedrock slope, the permanence of the creek, the

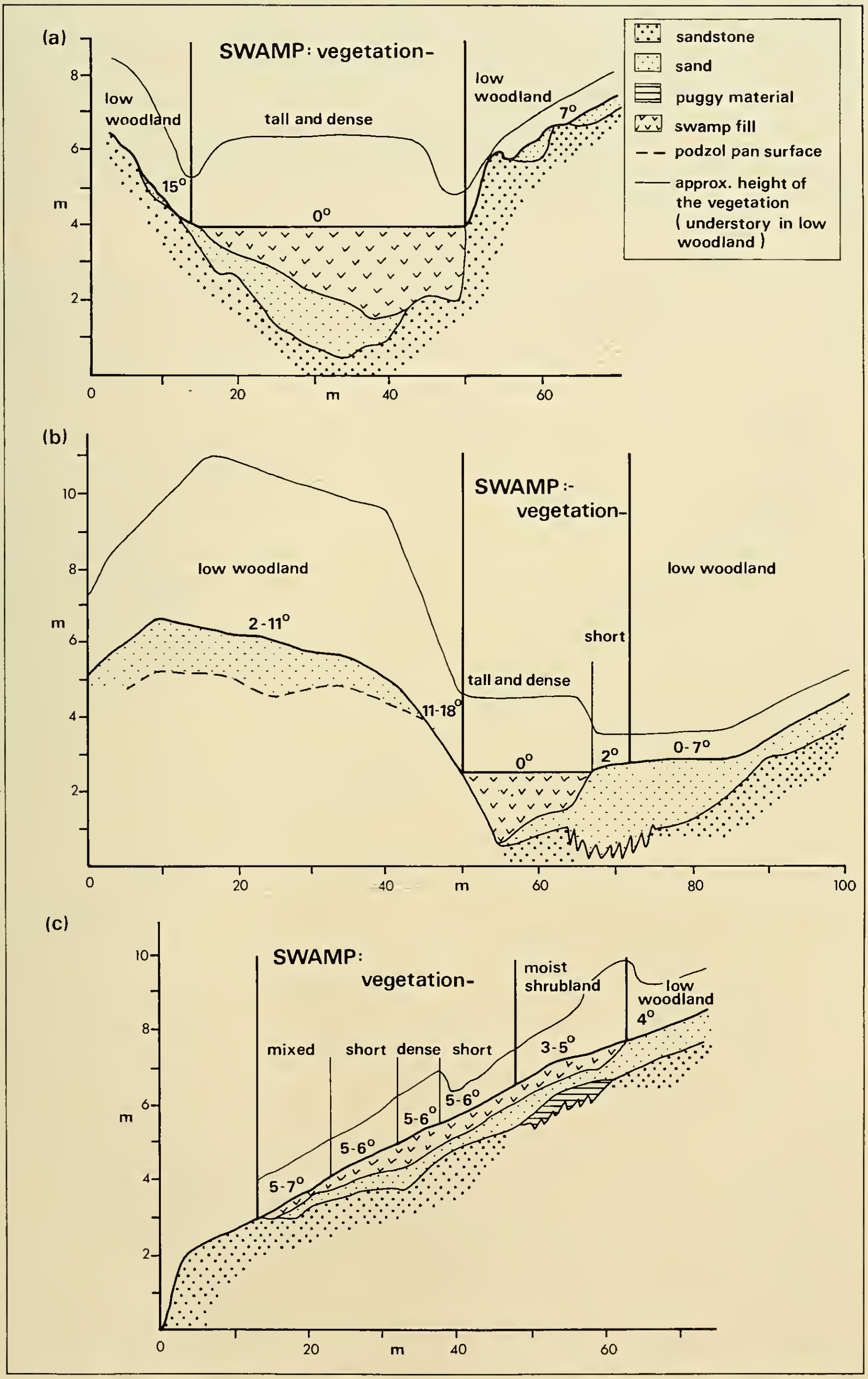

Fig. 7. Swamp sections: a) Swamp 21, valley-floor. b) Swamp 11, valley-floor. c) Swamp 14, valley-side.

distance from the creek, and the depth, thickness and extent of the puggy material. The type and extent of swamp vegetation on the hillslope is therefore very variable.

Swamp 13 (Fig. 8e) shows the zonation up the hillside. As usual, the tall and dense swamp vegetation is present on the valley-floor component. A change in slope from 0° to 2° and the presence of puggy material cause a rapid decrease in vegetation height to an area dominated by *Gymnoschoenus sphaerocephalus*. A gradual but still readily distinguishable change from short to mixed swamp vegetation, then to moist shrubland occurs as the soil becomes progressively drier upslope. At Swamp 13 the zone with mixed vegetation characterized by *Lepidosperma flexuosum* is only a narrow and discontinuous band.

Vegetation Types

Four distinct but intergrading swamp types occur in the Lambert Peninsula area. Listed in order of decreasing soil moisture, they are swamps with 1) tall and dense

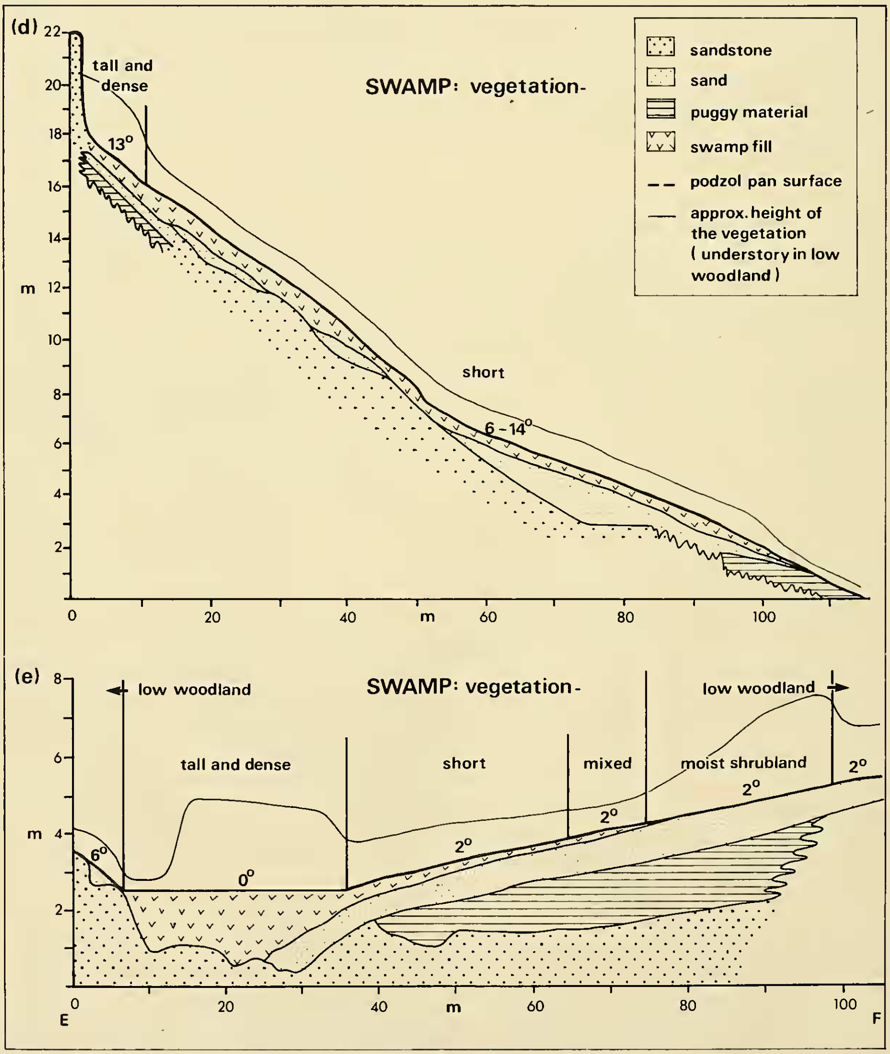

Fig. 8. Swamp sections: d) Swamp 4, valley-side. e) Swamp 13, composite.

vegetation, 2) dense vegetation, 3) short vegetation and 4) mixed vegetation. Moist shrubland is frequently associated with swamps and is included in this section.

Only nine species have been recorded in swamps with tall and dense vegetation but as the swamp type becomes drier, the number of species present becomes greater. This trend is partly reflected in Table 1 where only the most common species are listed.

TABLE 1

List of typical species present in the four swamp types and moist shrubland

	Swamps: vegetation —				Moist
	tall and dense	dense	short	mixed	shrubland
Utricularia cyanea R. Br.	X	X			
Banksia robur Cav.	X	X	X		
Baeckea linifolia Rudge	X	X	X		
Leptospermum juniperinum Sm.	X	X	X		
Aotus ericoides (Vent.) G. Don	X	X	X		
Gleichenia dicarpa R.Br.	X	X	X		
Gahnia sieberana Kunth	X	X	X		
Baumea arthrophylla or sp. aff.	X	X	X		
Empodisma minus (Hook.f) Johnson & Cutler syn. *Calorophus minor* Hook f.	X	X	X	X	X
Lepidosperma forsythii Hamilton		X	X		
L. longitudinale Labill.		X			
Cassytha glabella R.Br.		X	X	X	X
Epacris obtusifolia Sm.		X	X	X	X
Sprengelia incarnata Sm.		X	X	X	X
Banksia ericifolia L.f.		X	X	X	X
Viminaria juncea (Schrad.) Hoffmgg.		X	X	X	
Lepidosperma flexuosum Labill.			X	X	X
L. limicola N. Wakefield			X	X	
Schoenus paludosus (R. Br.) Poir.			X	X	X
Schoenus sp.			X		
Gymnoschoenus sphaerocephalus (R.Br.) Hook.f.			X		
Xanthorrhoea resinosa Pers. ssp. *resinosa*			X	X	X
Leptocarpus tenax (Labill.) R.Br.			X	X	X
Drosera spathulata Labill.			X	X	
D. pelata Sm. ex Willd.			X	X	
Xyris operculata Labill.			X	X	
Lycopodium laterale R.Br.			X		
Baeckea imbricata (Gaertn.) Druce			X	X	X
Leptospermum squarrosum Soland. ex Gaertn.			X	X	X
Bauera rubioides Andr.			X	X	X
Dillwynia floribunda Sm. var. *floribunda*			X	X	X
Hakea teretifolia (Salisb.) J.Britt.			X	X	X
Banksia aspleniifolia Salisb.			X	X	X
Lepyrodia scariosa R.Br.				X	X
Restio complanatus R.Br.				X	
R. fastigiatus R.Br.				X	X
Actinotus minor (Sm.) DC.					X
Angophora hispida (Sm.) Blaxell syn. *Angophora cordifolia* Cav.					X
Kunzea capitata Reichb.					X
Grevillea speciosa (Knight) D. McGillivray syn. *Grevillea punicea* R.Br.					X
Isopogon anethifolius (Salisb.) Knight					X
Petrophile pulchella (Schrad.) R.Br. syn. P. *fucifolia* (Salisb.) Knight					X
Persoonia lanceolata Andr.					X
Epacris pulchella Cav.					X

Two of the plant species which occur in swamps have interesting distributions (Fig. 4). *Banksia robur* occurs only in the southern and eastern corner of the area. Its absence from apparently suitable habitats in the northern swamps is difficult to explain, especially as it occurs immediately north of the peninsula in the Gosford district. The western swamps may be too dry. A very common swamp species in the Blue Mountains and south of Sydney, *Gymnoschoenus sphaerocephalus,* occurs only in the Salvation Creek catchment. Like *B. robur,* its absence from other swamps is unexplained, as apparently suitable habitats occur elsewhere on the peninsula.

Gahnia sieberana, by contrast, occurs in all suitable habitats on the peninsula and only the largest occurrences have been marked on Fig. 4. This bird-dispersed species appears to spread more rapidly than the wind- or water-dispersed *B. robur*, as mature individuals occur in moist places along the verges of the West Head Road.

Because of the anomalous distribution of some major species, the wide range of water tolerance of some species, and the importance of fire frequency on species distribution, it is necessary to divide swamp types on criteria other than species presence or absence. The four swamp types and moist shrubland were divided by the characteristic height and abundance of some of the larger species (Table 2). Swamp species such as *B. robur, Gahnia sieberana, Leptospermum juniperinum* and *Empodisma minus* become shorter and more scattered with a decrease in soil moisture. Species most abundant and vigorous in moist shrubland become progressively shorter and less dense with an increase in soil moisture, for example *Hakea teretifolia, Banksia ericifolia* and *Banksia aspleniifolia.*

The Specht classification (Specht, 1970) is not very suitable for describing the four swamp types. In the swamps in the wetter areas (vegetation tall and dense) species from the families Restionaceae and Cyperaceae combine to form a dense layer but a sparse layer of shrubs emerges above this mass (Fig. 9a). Specht's classification using the projective foliage cover of the tallest stratum has been rejected and the swamps have been classified by the dominant tallest stratum (Beadle and Costin, 1952; Forster, Campbell, Benson and Moore, 1977). Several structural formations in the Specht classification are needed to describe fully the range of swamps with short vegetation, although this type is readily distinguishable in the field.

A description of the four swamp types and of moist shrubland and conditions in which they usually occur is given below.

1. *Swamp: vegetation tall and dense* (Fig. 9a). Classification according to Specht (1970), tall closed-sedgeland.

   The water-table is near or above the surface for most of the year, as this swamp type is closely associated with creeks. The iron/organic fill is fairly free of sand and is 1-3 m deep.

   Gahnia sieberana is often the dominant species but it may be co-dominant with *Empodisma minus*. The dense *G. sieberana* and *E. minus* form a thick layer from the soil up to approximately 2 m. Scattered shrubs of *Leptospermum juniperinum, Baeckea linifolia* and heads of *G. sieberana* 3-4 m tall emerge above the dense layer. *Banksia robur,* if present, is usually 1.5-3.5 m tall and *Aotus ericoides* is usually only 1-1.5 m tall. All shrubs provide support for the weakly twining *E. minus*. The fern *Gleichenia dicarpa* is scattered or dense and up to 1 m tall. The dense *Gahnia sieberana* and *E. minus* may be interrupted by drainage lines where *Baumea arthrophylla* or sp. aff., *E. minus* and the small herb *Utricularia cyanea* are the only vascular plants present.

2. *Swamp: vegetation dense* (Fig. 9b). Classification according to Specht (1970) mid-height closed-herbfield.

   The water-table is less frequently above the surface than for swamps with tall

Fig. 9.
a) Swamp 21 — vegetation tall and dense. Dense *Gahnia sieberana* overtopped by scattered *Leptospermum juniperinum*.
b) Swamp 9 — vegetation dense. Canopy height more even than in (a). Broad leaved shrub is *Banksia robur*. The white zone at the edge of the swamp is *Hakea teretifolia* in flower (moist shrubland).
c) Swamp 4 (valley-side arm) — vegetation short. Rocks in the foreground are part of a 4 m high cliff. There is a sharp swamp/low woodland boundary.
d) Vegetation mixed. *Lepidosperma flexuosum* frequently forms the tallest layer and gives this swamp type a uniform appearance. Scattered *Hakea teretifolia* is visible.

and dense vegetation, as these swamps are associated with less permanent creeks or are at a greater distance from the main creek channel. The iron/organic fill is slightly sandier and is usually 0.5-1.5 m deep. Sand usually occurs between the iron/organic fill and the underlying rock.

E. minus and *Gleichenia dicarpa* frequently form a dense layer from the soil surface to between 0.5-1.0 m. A second but less dense layer composed of *Gahnia sieberana, Baeckea linifolia, L. juniperinum* and *Banksia robur* occurs at 1.5-2.0 m. Drainage channels, with *Baumea arthrophylla* or sp. aff. the commonest species, may be present. Plants from drier areas may be scattered throughout.

3. *Swamp: vegetation short* (Fig. 9c). Classification according to Specht (1970), mid-height closed-herbfield/herbfield, closed-heath/open-heath.

This swamp type frequently occurs on shallow soils with rock less than 1 m below the surface. Such soils provide only a small reservoir of water in dry periods and high water levels are maintained by flooding from drainage lines during wet periods and/or from water in puggy material. The iron/organic fill may be sandy and almost absent or up to 1 m deep, but it is commonly between 0.3-0.6 m deep.

No dominant species occurs in this swamp type, although in individual swamps one or more dominant species may be recognized. As the species composition is so variable, this type is best recognized by the height and abundance of some of the most constant species (Table 2). *Gleichenia dicarpa* may be dense, in dense patches or scattered. The average height of the vegetation is commonly 0.5-1.0 m and it is usually less thick than the vegetation of the two preceding types.

4. *Swamps: vegetation mixed* (Fig. 9d). Classification according to Specht (1970), mid-height herbfield/open-heath.

This swamp type often occurs in shallow sandy soils approximately 0.2-0.5 m deep and it frequently forms a zone between a rock shelf and moist shrubland. Swamps with mixed vegetation are subject to widely fluctuating soil moisture and to drier conditions than other swamps. The iron/organic fill may be reduced to a thin sandy skin or up to 0.3 m deep.

The vegetation is a mixture of species occurring in swamps and moist shrublands. No dominant species occur in this swamp type, but *Lepidosperma flexuosum* frequently forms the tallest layer between 0.75-1.0 m and gives it a characteristic and often uniform appearance. The *L. flexuosum* layer is often only interrupted by a few scattered shrubs, usually *Banksia ericifolia, Banksia*

TABLE 2

Abundance and height of species which characterize swamps with vegetation: 1) tall and dense 2) dense 3) short 4) mixed, and moist shrubland.

	Swamps: vegetation —				Moist shrubland
	tall and dense	dense	short	mixed	
Banksia robur					
Abundance	scattered	scattered	very scattered	—	—
Height (m)	1.5-3.5	1.5-2	<1.5		
Leptospermum juniperinum					
Abundance	scattered	scattered	very scattered	—	—
Height (m)	2.5-4	1.5-2	<1.5		
Gahnia sieberana					
Abundance	dense-scattered	scattered	very scattered	—	—
Height (m)	2-3	1.5-2	<1.5		
Empodisma minus					
Abundance	dense-scattered	dense-scattered	scattered-very scattered	very scattered	very scattered
Height (m)	1-2	0.5-1	0.25-0.75	0.25	0.25
Hakea teretifolia					
Abundance	—	—	very scattered-scattered	scattered	scattered-dense
Height (m)			<1	<1	1-2.5
Banksia ericifolia					
Abundance	—	usually absent	very scattered-scattered	scattered	scattered
Height (m)		1-2	<1	<1	1-2.5
Banksia aspleniifolia					
Abundance	—	—	very scattered-scattered	scattered	scattered
Height (m)			<1	<1	1-1.5

"—" = absent

aspleniifolia, Hakea teretifolia or *Viminaria juncea*. Only one species from the wettest swamp type is sometimes present. *E. minus* is occasionally scattered throughout but is usually less than 0.25 m tall.

5. *Moist shrubland*. Classification according to Specht (1970), open-heath/open scrub and Pidgeon (1938), moist scrub.

   The soil surface is sandy and very little iron or organic material is present. The soil is intermittently moist and puggy material usually occurs under these shrublands.

   The moist shrublands are usually dominated by *Hakea teretifolia* or more rarely by a mixture of *H. teretifolia, Banksia aspleniifolia, B. ericifolia, Persoonia lanceolata* and *Grevillea speciosa*. *H. teretifolia* is usually about 2 m high and fairly dense but it may become shorter and more scattered near the boundary with swamps. An understorey of herbs and shrubs, especially *Bauera rubioides*, may be present but often much of the ground is bare. Occasionally a *Xanthorrhoea resinosa — Banksia aspleniifolia — Bauera rubioides* shrubland occurs. The average height of this type is only 0.5-0.75 m and may be denser than the *H. teretifolia* shrublands. *H. teretifolia*, up to 2 m tall, is often scattered through this second moist shrubland type.

The Swamp Fill

The outlet of valley-floor and composite swamps occurs at a fill/erosion transition zone along the creek profile. In the fill or swamp zone only local and minor erosion takes place. Deposition of the dissolved, dispersed and solid load is partially caused by the decrease in slope, but organisms also decrease the stream competence.

The dense tussocky vegetation in valley-floor swamps probably reduces the water velocity and inhibits erosion of the swamp. Dense *Empodisma minus* and *Baumea arthrophylla* or sp. aff. trap sand and a flocculent, reddish-brown material at the outlets of valley-floor and composite swamps. The resulting barrier forms an efficient dam which frequently has a large pool built up behind it.

A large amount of this flocculent, reddish-brown material occurs in creek channels, semi-permanent pools and in the upper layer of swamp soils. A sample of the flocculent material, and a sample of ferric hydroxide were analysed by atomic absorption spectroscopy. The material from the swamp contained 60% as much iron on a dry weight basis as the sample of ferric hydroxide. Iron bacteria are present and can aid the deposition of iron by oxidizing ferrous compounds to ferric oxide which is deposited in the bacterial sheath (Stevenson, 1967) or by metabolizing the organic molecule with which the iron is complexed (Skerman, 1967). Algae such as *Botryococcus* sp. and *Closterium* sp. are fairly abundant and *Closterium* is often common in boggy, acid waters (Prescott, 1969). This flocculent mass may be approximately 0.5 m deep in valley-floor swamps but on valley-side swamps it may be only a thin skin. No attempt has been made to undertake a detailed study of the microbiology or chemistry of these interesting communities.

As a result of the complex depositional history and an intricate sedimentation pattern, the iron/organic swamp fill may vary over short distances. This fill does however have many characteristic features. It is acid (pH 4.5-5.5) throughout. The upper 0.5 m or less consists of the reddish-brown flocculent mass and plant remains, but with increasing depth the fill becomes firmer and the colour changes to olive-black or black. The smell of hydrogen sulphide also increases with depth. The fill appears to have a high iron and organic content throughout and has a silky feel. The flocculent mass on the surface contains the least amount of sand. Layers with varying sand and gravel content occur throughout, but there is usually a sharp break to an organicallystained sand which sometimes occurs immediately above bedrock. Charcoal is present in the fill. In valley-floor swamps and the valley-floor component of composite swamps the iron/organic fill is usually 1-2 m deep. In valley-side swamps the fill is shallower and more sandy.

Crayfish burrows and the resulting piles of soil are abundant in some swamps. They mix the sediment layers and even contribute to the formation of irregular hummocks.

Discussion

The physiographic asymmetry of the Lambert Peninsula has resulted in an asymmetric distribution of vegetation types. The rugged topography of the western side is not generally suited to the formation of shrublands, swamps or podzols, while the extensive areas with a gentle slope on the eastern side provide suitable conditions. Swamps on the western side are generally drier than those on the eastern side (Table 3). For example, the vegetation of all eastward flowing valley-floor swamps is tall and dense but in the three western valley-floor swamps (Swamps 15, 16 and 17) tall and dense vegetation is absent or unimportant.

TABLE 3

Topographic and vegetation swamp types

	Swamps: vegetation —				Moist
	tall and dense	dense	short	mixed	shrubland
Valley-floor swamps					
1	X				
4	X				
11	X				
15			X		X
16			X		X
17	—				X
21	X				
22	X				
25	X				
26	X				
Valley-side swamps					
2			X		X
3			—	X	X
4			X		
5				X	X
6		X	—	—	X
7			—		X
10	X				X
12			X		X
14		—	X	—	X
20			—	X	X
27			—	X	X
Composite swamps					
8	—	—	X		X
9	—	X	—		X
13	X		—	—	—
18		—	X		X
19	X		—		X
23			X		X
24	X			X	—

"X" = an important component
"—" = present but unimportant

On the gently sloping plateau surface of the peninsula the influence of aspect (varying exposure to the prevailing winds and sunlight) is not as great as Pidgeon (1938) reports for the Hornsby Plateau — an area which includes Lambert Peninsula. She relates the distribution of moist scrub (moist shrubland) to inefficient drainage and rigorous conditions of exposure. However low woodland can grow in more exposed conditions than occur on the plateau surface and extensive areas on the upper, exposed western slopes are indeed covered by this formation. Exposure appears to modify the height and floristics of some of the vegetation units, but the basic pattern of swamp, shrubland and tree covered areas is determined by soil depth and moisture, which are, in turn, controlled by the lithology and micro-topography. Even the structure and floristics of the podzol vegetation are functions of the soil conditions, as the characteristic vegetation of these soils is only slightly altered by the degree of exposure.

The different structural formations are probably very stable, even in terms of millennia, and can thus be considered as climaxes (Beadle and Costin, 1952). Despite this stability, major climatic changes appear to be responsible for swamp development and destruction, and even short term (tens of years) fluctuations can lead to temporary boundary changes. For example, a series of dry years enabled eucalypts (probably *Eucalyptus sieberi* L. Johnson) to become established in the valley-side components of Swamps 13 and 9 and these grew to about 5 m before the water-table rose and killed them.

Fluctuations are however most easily seen on the rock shelf/moist shrubland boundary, as the conditions enabling the development of swamps and moist shrublands on these shelves seem to be more delicately balanced. The dry summer of 1974-75 probably illustrates the conditions which lead to boundary oscillations and in more severe conditions to permanent major changes. During this summer the algal, sand and root mat at the rock boundary cracked vertically and up to 15 cm of the soil fringe lifted 5 cm off the rock surface. When only a thin layer (0.5-1.0 cm) of moss, algae and herb roots covered the rock shelf, shrinkage and cracking of the mat revealed the rock beneath. In moist areas the smooth gelatinous texture of the surface changed to a rough one as the algae and bacteria dried.

Although individuals of only one plant species (mature *Banksia ericifolia*) were noticed dead as a result of this drought, it is not difficult to imagine drier conditions, particularly combined with fire, leading to the removal of the vegetation and shallow soil from rock shelves. As vegetation and micro-organisms die, soil binding would be reduced (Harris, Chesters, Allen and Attoe, 1964) and cracks in the soil would enable fire to burn organic matter well below the surface. Heavy rain or even wind could rapidly remove the resulting loose, unprotected soil. A sequence similar to this probably caused the death of vegetation in vacant gnammas (Twidale, 1975) but a widespread retreat of vegetation from rock surfaces would probably require a catastrophically drier climate than at present.

Heavy rains appear to cause little damage to rock/vegetation boundaries or to swamp vegetation if the vegetation has not been dried out or burnt beforehand. A moister climate than at present and a low fire frequency may result in the vegetation advancing across the bare rock surfaces downslope of moist shrublands.

Formation and destruction of valley-floor swamps may be closely linked with climatic changes. Destruction or scouring of deep channels may occur in the dry periods by a sequence similar to that described for rock shelf vegetation, but the conditions would have to be very dry to scour a whole valley-floor swamp to bedrock. The presence of zones of gravels on bedrock beneath some swamps could be explained either by destruction of the swamp, or by the lateral migration of deep major drainage channels which are sometimes present. Although more detailed stratigraphic studies and dates are needed before any general statements can be confidently made, the valley-floor swamps around Sydney appear to be quite young, with dates from the Blue Mountains (Stockton and Holland, 1974) and south of Sydney (Dury and Langford-Smith, 1968) ranging from 4110 ± 100 years before the present (B.P.) to 17050 ± 600 years B.P. This suggests that deposition occurred in the Holocene and terminal Pleistocene. Geographical and climatic conditions probably favoured swamp development before these dates and the present swamps may be representatives of a cycle of swamps which have built up, been scoured or even destroyed, and subsequently re-formed.

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APPENDIX 1

Podzol grid references (G.R.)

Podzol No.	Map	G.R.
1	Hornsby 9130-1V-S	371716
2	"	366718
3	"	365725
4	"	364739
5	"	373742
6	"	376742
7	Mona Vale 9130-1-S	383742
8	" "	391755
9	" "	389762
10	" "	382768
11	" "	384773
12	" "	389779
13	" "	384778
14	" "	384780
15	Broken Bay 9130-1-N	379783
16	Cowan 9130-IV-N	360792
17	"	365796
18	"	372796
19	"	376796
20	Broken Bay 9130-1-N	399781
21	" "	401787
22	" "	393792
23	" "	399799
24	" "	392805
25	" "	398810
26	" "	406808
27	" "	413812
28	" "	408816

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Appendix 2

Swamp grid references (G.R.)

Swamp No.	Map	G.R.
1	Hornsby 9130-1V-S	366719
2	"	368732
3	"	360735
4	"	375741
5	"	369750
6	Mona Vale 9130-1-S	386754
7	" "	391753
8	" "	389762
9	" "	384770
10	" "	388771
11	" "	389779
12	" "	385776
13	" "	383779
14	Cowan 9130-IV-N	376783
15	"	359792
16	"	375798
17	Broken Bay 9130-1-N	386794
18	" "	400781
19	" "	411787
20	" "	391789
21	" "	396794
22	" "	399799
23	" "	440806
24	" "	397810
25	" "	406808
26	" "	413812
27	" "	409821

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